FLEXWALL HYDRAULIC HOSE REPLACEMENT IN THE NASA GLENN 10- BY 10-FOOT SUPERSONIC PROPULSION WIND TUNNEL

PRESENTED AT THE 99TH MEETING SUPERSONIC TUNNEL ASSOCIATION, INTERNATIONAL HOSTED BY: THE BOEING COMPANY ST. LOUIS, MO APRIL 6-8, 2003

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INTRODUCTION

This paper describes the flex-wall hydraulic hose replacement at the NASA Glenn Research Center 10- by 10-Foot Supersonic Propulsion Wind Tunnel (10x10 SWT) and the events that occurred during this rehabilitation project. Overall facility capabilities and system operational details are presented. Lessons learned and recommendations for similar facility applications are also described.

1. FACILITY OVERVIEW

1.1. Overview: NASA Glenn 10- by 10-Foot Supersonic Propulsion Wind Tunnel

The NASA Lewis 10- by 10-Foot Supersonic Propulsion Wind Tunnel (10x10 SWT) is a variable density, continuous flow propulsion wind tunnel. The facility layout is shown in Figure 1. The facility is fully operational and operates supersonically at Mach numbers from 2.0 to 3.5 in 0.1 increments. The facility provides a continuous flow capability using two drive systems to cover the operational Mach number range. The main drive is an 8-stage axial compressor driven by four 41,500 hp electric motors; the secondary drive is a 10-stage axial compressor powered by three 41,500 hp electric motors. The main drive system is used to set test section Mach numbers up to 2.5; above Mach 2.5, both the main and secondary drive systems are used. Mach plate systems are used to expand the useful supersonic test range of the facility from approximately Mach 1.6 to 4.1.

The 10x10 SWT is the premier high-speed aeronautic and space propulsion research test capability in the United States. The facility is equipped with a full suite of specialized test support capabilities, instrumentation and data acquisition and analysis equipment. These systems include large capacity high-pressure and vacuum air supply systems, liquid and gaseous fuel systems (eg. turbine engine fuels, hydrogen and oxygen), and other systems. The most unique characteristic of the 10x10 SWT is its ability to operate as both a closed loop aerodynamic test facility and an open loop propulsion test facility. In the open loop propulsion mode, air enters through the air dryer, makes one pass through the test section, and the tunnel air and engine exhaust is discharged through an exhaust muffler to run actual hot, fuel-burning propulsion systems.

In order to meet the demand for subsonic test capability at NASA Glenn, a program was instituted to develop the use of the 10- by 10-Foot Supersonic Propulsion Wind Tunnel for subsonic testing. This was accomplished by operating the main drive system at lower than normal rotational speeds and by running the drive system using either one, two, three or all four of the electric drive motors. This is an extension of similar work completed at the NASA Glenn 8- by 6-Foot Supersonic Wind Tunnel. Also, very low test section airspeed conditions (below Mach 0.1) are set using the air blowers in the facility air dryer building. Verification and calibration tests were performed to demonstrate that the facility could be safely, reliably, and accurately operated over the subsonic Mach number range of 0 to 0.36 by using either the facility air dryer air blowers or the main drive compressor.

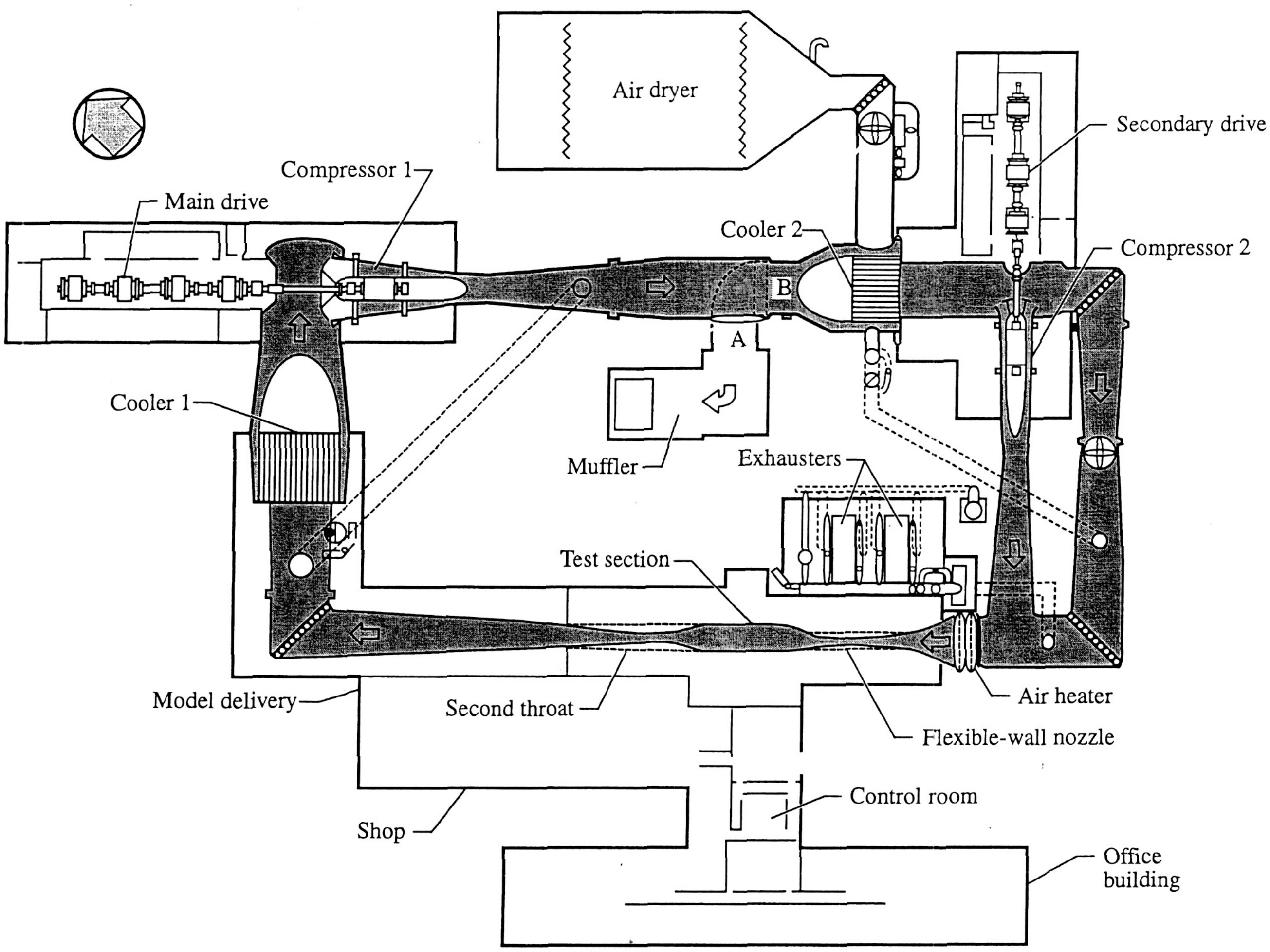


Figure 1: Layout of the 10- by 10-Foot Supersonic Wind Tunnel (10x10 SWT).

1.2. Details: NASA Glenn 10- by 10-Foot Supersonic Propulsion Wind Tunnel

Selected additional data describing more details of the specialized capabilities and systems can be found in the appendix in section 4.

2. Hydraulic Hose Replacement Project

2.1. Project Overview

The reason for this project was three fold. First, strict interpretation of the NASA Glenn safety guidelines indicated that the hoses were out of compliance. The flex-wall hoses were not tagged and were not being re-certified on a prescribed cycle as required. Second, the age of the flex-wall hoses, some of which had been in the system for ten years, warranted the replacement of all of the approximately 400 hoses in the system. The flex-wall hoses are subjected to approximately 400 pressurization cycles per year at operating conditions of 850 PSI and 160 degrees F. And third, routine inspections of the hydraulic oil and the presence black residue, which was assumed to be from the flex-wall hoses in the system and an indication that the flex-wall hoses may be breaking down.

To plan the project, a preliminary meeting was held in February 2002 with the Facility engineer, test engineers supporting the Research Testing Division, and lead representatives from the maintenance contractor that supports the wind tunnel areas. The decision was made to utilize in-house manpower resources to do the entire job, including the empting of the hydraulic tank and cleaning as required and changing the hoses on the system as well as the refilling and bringing the system back on line. The primary reasons were cost and schedule and our desire to use this project as a unique training opportunity for the personnel recently assigned to the tunnel. It was decided to push to complete the work by April 2002, which was the original schedule.

2.2 Flexible Wall Nozzle System Description and Capabilities

The 10x10 SWT flex-wall system controls supersonic air speed velocities in the tunnel over the Mach number range of Mach 2.0 to 3.5. The flex-wall nozzle consists of two, type-322 stainless steel side walls 10 feet high, 78 feet long, and 1 3/8 inch thick. The walls are supported by casters and sealed against the floor and seal nozzle plates with inflatable seals. The two walls are each actuated by 27 stations of hydraulically operated screw-jacks. The entire system is computer operated from the control room. The side walls can be positioned very accurately in very small increments to produce variations of 0.1 Mach in the test section. The floor and ceiling nozzle plates are fixed.

2.2. Hydraulic System Description

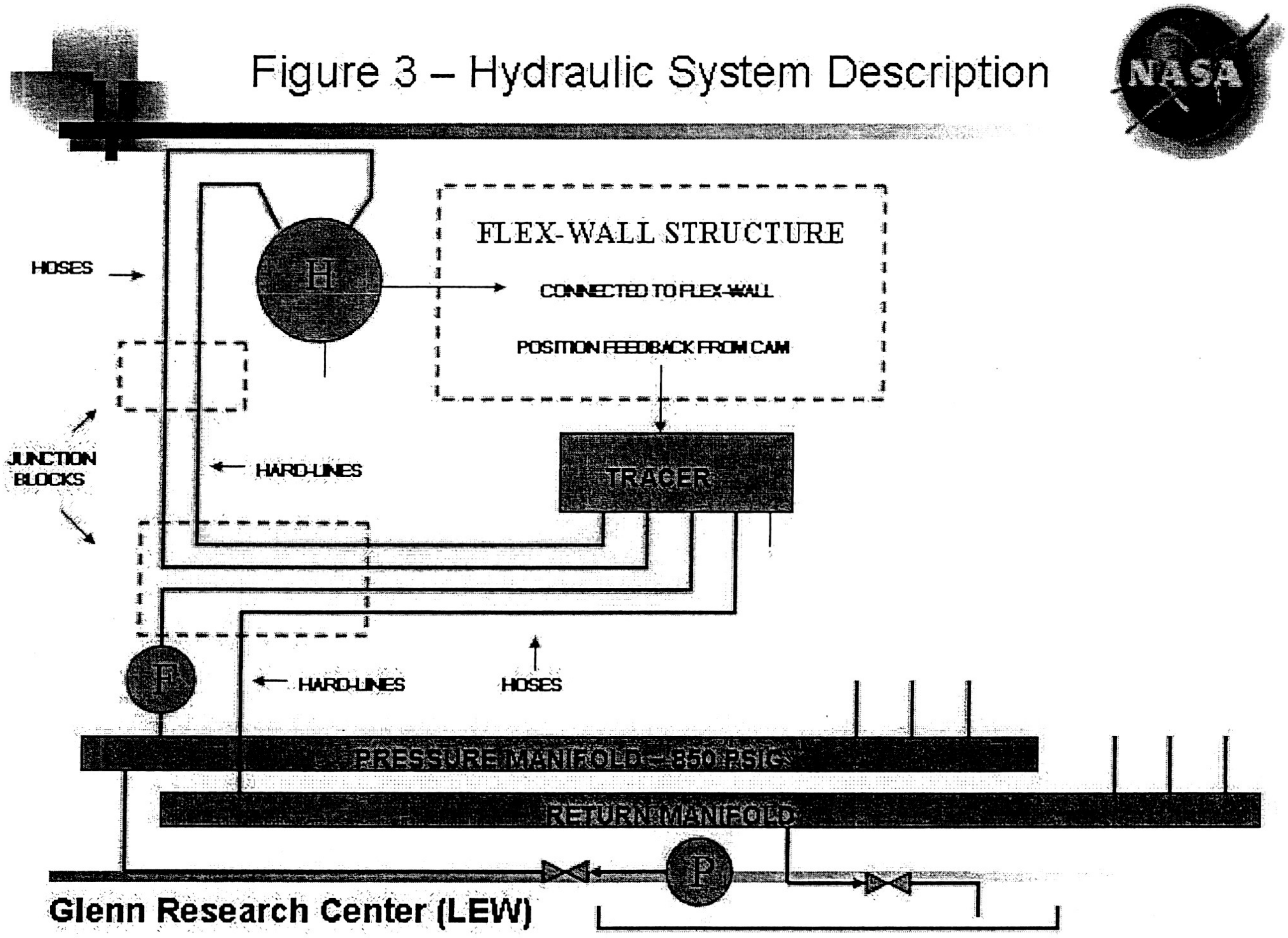
A simplified sketch of the system is shown in Figure 3. The system is composed of two hydraulic systems. One system operates each wall of the flex-wall nozzle independently. Both systems are essentially identical. Each system has a 1200 gallon reservoir which is filled with Mobil DTE Light hydraulic oil. There are five hydraulic pumps in each system powered by 30 hp electric motors. The main supply manifolds run the full length of each flex-wall, which is 78 feet in length. System pressure is maintained by a back pressure relief valves, which are set at 850 PSI.

Each flex-wall has 27 individual jacking stations. Each station has a tracer valve, a cam mounted on a common shaft that runs the length of each flex-wall, and upper and lower hydro-motor actuators and screw jacks. The tracer valves use the cam contours to determine how far the wall should move at each of the different 27 stations, and send direct hydraulic fluid to the hydro-motor actuators. The hydro-motors provide the power to the screw-jacks that create the thrust to move the flex-wall structure.

The contour of each cam is precisely machined at each station create the flex-wall nozzle dimensions necessary to establish the desired Mach number conditions. In this way, the flex-walls are very accurately positioned such that the coordinates are maintained to within .005 of an inch over the entire length. In addition, permissive devices are built into the system to insure that the system is not overdriven beyond the desired settings and to also insure that the walls are not driven asymmetrically too far forcing the wall into a "tilt" binding condition.

As each flex-wall has 27 actuator stations, each station has an upper and lower actuator, and each actuator has eight individual hoses, there are a total of 432 hydraulic hoses in the system. The majority of the hoses are 1 inch in size. The hydro-motor and tracer valve drain hoses are ½ inch in size. Each station also has a ten micron absolute filter to clean the oil and maintain an NAS Class 6 or better to avoid fouling of the tracer valves.

The oil is drained from the hydro-motors through the tracer valve and into the return manifold and back to the reservoir. An independent cooling system is piped into each reservoir and is set to maintain the oil temperature of the oil below 155 degrees F.



2.3. Hydraulic Hose Selection and Policies at NASA Glenn

Facility and model support systems are two areas at NASA Glenn where hydraulic hoses are highly utilized. In order to properly select a hose for a system, the fluid medium, operating temperature and pressure, and the environment the hose will be subjected to must be defined.

Of the many fluid mediums used in the facility and models, oil is the one that can vary significantly. Facility and model systems use both petroleum based and synthetic based oils. The operating temperature and pressure for facility and model systems can range from ambient to 800 degrees F and above and 100 to 3000 PSI and above. The higher temperatures and pressures would most likely be driven by model support system demands. After determining the oil base and the amount of flow through the hose, the environment where the hose will be used has to also be considered. The hose could be in an environment where high air temperature, vibration, and air loads make it hard for the hose to survive. If the hose is in the tunnel it could see high temperatures from model exhausts or from the heat from tunnel systems. The hose may also have to deal with dynamic situations caused by shock reflections and/or fast moving components.

Once the fluid, operating temperature and pressure, and the environment are determined, selecting a hose is straightforward. Most hose manufacturers have tables that will show compatibility between most fluids and hose materials. The manufacturer usually will list the hose by the type of fluid medium, such as hydraulic or fuel. Once the type of hose material is located, then the working temperature and pressure will define the hose construction. The hose construction will also have to take into account the environment where the hose will be used.

The hose fitting selection is also kept straightforward. If the new hose is a replacement, then the original type of fittings will be used. Hoses do not have to have the same fitting on each end. You can have a joint industry conference (JIC) fitting and a national pipe thread (NPT) fitting on either end of the hose. There is a strong attempt to connect similar fittings to one another such as JIC to JIC, NPT to NPT, and Army/Navy (AN) to AN. Because the JIC fitting is very similar to the AN fitting, one could debate that since these are going to be used on models and not flight hardware, that you could connect JIC to AN. At this moment in time the effort is to connect similar fittings together.

Current safety guidelines at the Glenn Research Center (Glenn Safety Manual, Glenn Re-certification Handbook) require inspection and re-certification for high pressure flexible hoses (>200 psig) at defined cycles. These requirements include an annual external visual inspection of all flexible hoses and an annual internal visual inspection of pneumatic hoses (eg. using a borescope). All flexible hoses must be re-certified every 5 years – including an internal visual inspection and a pressure test at maximum allowable working pressure (MAWP) levels. Other requirements include restraints for hoses longer than 6 feet, proper tagging, and maintaining inspection and conformance records on file.

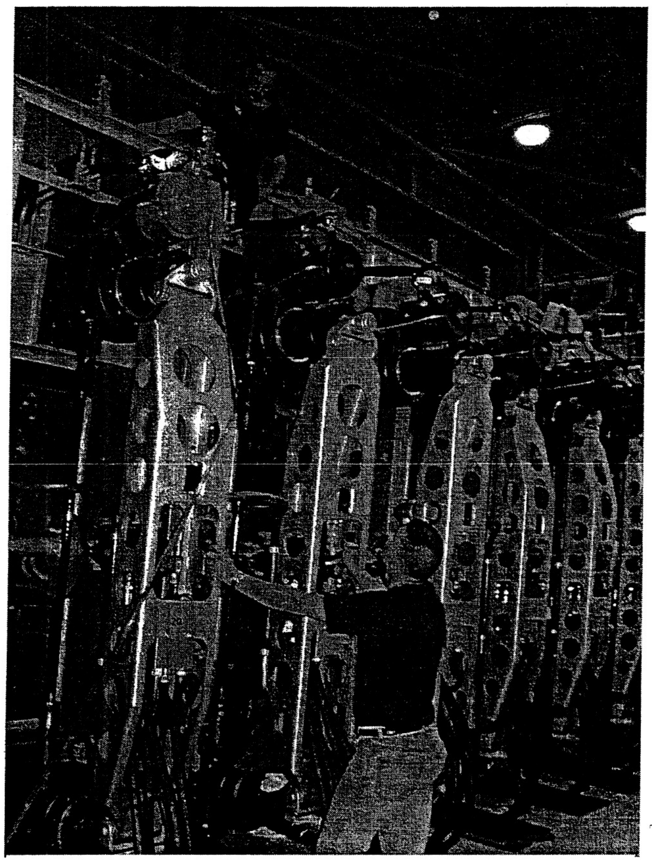
With the over 500 high pressure flexible hoses in use at the 10x10 SWT (most of which are installed on the flex-wall nozzle), adhering to the above requirements would require a significant amount of manpower and would be very costly. So, an alternative plan for flexible hose re-certification and inspection at the 10x10 SWT was proposed to, and accepted by, NASA Glenn safety personnel.

The agreed upon alternate plan includes an annual external visual inspection of all flexible hoses and a re-certification of all pneumatic flexible hoses every 5 years (approximately 40 hoses). In addition, the agreement was made to re-certify six hoses from the flex-wall and at least 2 hydraulic hoses from every other support system at the 10x10 SWT systems every 5 years. The plan calls for corrective actions to be taken if problems are found.

To justify the agreed upon alternate plan, several factors were noted that supported the reduced inspection and re-certification cycles. Most, if not all, of the flexible hoses are being used at pressures much less than the hose pressure rating. All of the hoses are located indoors. Generally, the hoses are only "in-service" (undergoing pressurization cycles) during periods of tunnel operation. Historically, the hoses at the 10x10 SWT have demonstrated an extremely long life. For example, some of the hoses on the flex-wall were nearly 50 years old and still in apparently good condition.

2.4. Replacement Project Events and Results

The Mobil DTE Light hydraulic oil in the system was removed by a pumper truck that was brought in for the purpose. As discussed previously, the condition of the oil was one factor that had prompted this entire effort. The oil seemed to be literally black with a residue that was assumed to be evidence that the hoses in the system were breaking down. The cleanliness of the tanks was surprisingly good. The anticipation had been that there would be a heavy residue in the bottom that would have to be cleaned out by hand. There was a thin film that was wiped off the surfaces, but no serious build-up.

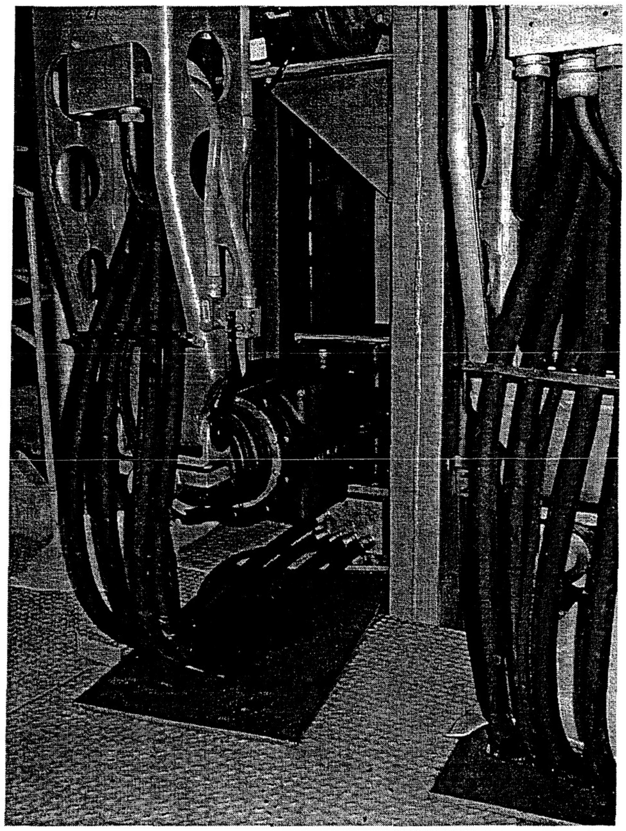


Hydraulic Jacking Stations, North Flex-wall

The hoses were purchased through our local support service contractor from Shields Wright Rubber. On inspection, it was found that there was one hose too few. The manufacturer made up that hose and completed the order. The facility technicians had taken a survey of the hoses required to do the job with diameter and length of each at specified stations. There was a delay in installation of the hoses because the original survey overlooked one hose at each station that was difficult to see. These hoses (54 each) were ordered and delivered within one week. During the effort to replace the hoses, it was discovered that the hoses at the top connection blocks in the hydro-motor supply/return lines were welded in place on the south side of the flex-wall. New blocks were fabricated and installed. It was also discovered that the top drain line from the hydro-motors had an unusual fitting on the downstream end. These fittings were replaced with standard AN fittings and new couplers installed to accept the new fittings. The hose connections were leak checked and continuity checked to insure system integrity.

After the reservoirs were pronounced clean, they were closed, except for the top hatches. Each opening was re-gasketed and sealed. New Mobil DTE Light was ordered from Campbell Oil at the cost of $4.44 per gallon. The first order was six totes (a tote is a heavy plastic bladder in a wire cage filled with 320 gallons of oil). A transfer pump was borrowed from our central process systems organization that is commonly used for transfer of hydraulic fluid. New filter elements were ordered for the transfer pump. The pump was run for a few minutes with the oil going into a waste barrel until the oil began to run clear. Three totes were emptied into each tank. This was not sufficient, so another tote was ordered. An additional six 55 gallon barrels were eventually ordered also to fill the tanks to the proper level. A lot of oil was used to fill the system during the flushing and the air removal operations, and another tote was delivered and used to maintain the proper level.

After the filling operation was complete, each hydro-motor was bypassed by installing a union between the hoses so that the system could be flushed without the hydro-motors in the system. Oil samples were taken from the totes before the filling was done and "new oil" cleanliness was assured. After the fill, another sample was taken from each tank. Initial samples were "dirty". The samples had been taken from a tap on the return line to the tanks. Glenn systems engineers recommended that samples be taken downstream of the filter stations to get a more representative sample. These samples were better, but still not good. NAS Class 5 – 6 was the goal. Results were 8 – 9. After some effort, without attaining the desired cleanliness, the 54 filters in the system were removed and cleaned. At this point, the filters in the flex-wall oil cooling system were replaced with new elements and this system was locked on to assist in the cleaning. After extensive flushing, both the north side and south side systems attained NAS Class 5 – 6 as desired.



Flex-wall Lower Hydromotor

At this point, the hydro-motors were reinstalled into the system for a system checkout and to continue flushing the system through the hydro-motors. When attempts were made to operate the main pumps, over-travel permissive devices on the tracer valves kept shutting the system down after a few seconds. An attempt was made to jumper out these permissive devices, but all that was accomplished was to burn out a circuit that was not designed to handle that many over-travel trips at once. Work to clear the air out of the north wall system was initiated. Difficulties were encountered when attempts were made to fill the system from the high point hose connections. At this point, it was suspected that the pressure relief valve that is used to regulate system pressure was leaking back into the main tank, not allowing the system to fill properly. Attempts to correct the leak were deemed to be too expensive (from a manpower perspective). They could also result in a worse situation because it is likely that a relief valve replacement could not be obtained that would fit into the system without serious delays (the unit is at least 50 years old). A decision was made to drill and tap the upper hose connecting blocks to allow filling at each of the 54 high points through a ½ " NPT nipple/cap arrangement. Since the cap and nipples were stainless steel, a galling problem was created with the removal of the caps. A decision was made here to replace all the caps with ball valves. After this work was completed, attempts were made to get the air out of the system using these valves with only partial success.

As a result of detailed inspections, the mantenance crew discovered that the routing of the hard lines at the 54 stations was not consistent. Every third station was apparently routed somewhat differently due to the peculiarities of the structure of the facility. It was also realized that certain dual hydro-motor stations, ten on each side, actually operated in the reverse of the rest of the stations. The maintenance crew then checked each station for proper hard line routing. The results showed a serious miss-routing problem. A hose routing spreadsheet was then generated by the facility engineer and provided to the maintenance crew that detailed each station and the maintenance crew went through the 27 stations and correctly hooked up each station. There were at least half of them that were routed wrong. It seems that the port/hose identification was not done properly at the start of the project, which created a really frustrating situation. After all the stations had been correctly routed, the system began operating properly on the first attempt. The stations on the South Wall stations were also corrected with the same positive result. Both sides were operated with the walls moving for some time to insure that the air had been cleared from the system. Oil samples were also taken to assure cleanliness.

As the project neared completion, additional oil samples were taken and analyzed. The results indicated that the north side system was at the NAS 5-6 level, but the south side needed more flushing. After additional flushing, the results from the south side sample were very acceptable.

With this sample clearing the system for acceptance, the flex-wall hydraulic system rehab effort was completed. The maintenance crew performed a final calibration check of the flex-wall coordinates to confirm that the wall is still within tolerance after this major rehab effort.

HISTORICAL NOTE: When the hoses were in the process of being removed from the system, it was noted that the majority of them were Aeroquip hoses and that they had been in the system, for the most part, for about 50 years. Aeroquip, now an Eaton Corp. Division, was contacted and given this information. The head of the hose division, who is stationed in Toledo, Ohio, asked if they could visit the lab with a photographer, and document the system and have a representative sample of the hoses. For this visit two sets of hoses were saved and put aside. After two attempts to schedule a visit were thwarted by other business, they have yet to be able to make their visit. The Eaton company is expected to do some analysis on the hose and give us some indication of the condition of these hoses in light of the estimated cyclic life of the hoses. The facility engineer has estimated about 400 cycles per year at 850 PSI maximum. System temperature is limited to 155 degrees F. This information will be extremely valuable as our maintenance procedures and schedules continue to be reevaluated.

3. CONCLUSIONS

3.1 Miscellaneous Observations and Notes

- Prior to the work on the flex-wall system, several people were contacted who had worked in the 10x10 SWT from the time it had begun operation. Some people were directly involved in the bringing of the facility "on-line" in 1954. They indicated early-on that the biggest problem they encountered at that time was getting the air out of the system. They commented that it had literally taken them months to solve that problem. The last time the system was drained was in 1976. The majority of the 432 hoses in the system had been in place since the facility first started operations in 1954. Every hydro-motor in the system was rebuilt in 1975. Although all the systems in the tunnel were reviewed and documented around 1990, the flex-wall hydraulic system was not included in this process.

- A problem became apparent after the pumper truck emptied both of the reservoirs. After the reservoirs were emptied, there was still over 100 gallons of oil in each manifold that needed to be drained into the tanks. This task was accomplished by running flex hoses from the downstream end of the return manifold and the bleed line just downstream of the main pumps back into the reservoirs and then breaking several lines at the high points. After this was done, the drain valves were installed in the 90 degree blocks in the main return lines just before it goes in the tanks. This should ease the problem in the future.

- During the effort to remove the air from the North wall hydraulic system, a ½ " NPT hole was created in the upper hose blocks at each pass-thru to allow access to the high point of each station. The hole was threaded and pipe nipples were installed with caps. To allow us to bleed the air more effectively, ball valves were installed at each high point. Although these valves are still in place, it is the opinion of the engineering team that they serve no purpose at this time, except to provide 108 more potential leak paths for the hydraulic oil. These valves and the nipples will be removed and the hole plugged to minimize leakage. This will be done at the convenience of the crew.

3.2 Lessons Learned and Recommendations

Assure proper documentation and configuration control. A complete and detailed documentation of the flex-wall system and hydraulic hose routing arrangement should be done when funding is available. The lack of this kind of detail information created several delays during the hose replacement project that could have been avoided. This documentation should be available for any future work on the system.

Verify proper hose routing. The preexisting hose routings should be properly documented before any hoses are removed. As the old hoses are removed, each hose should be properly identified and marked. The new hose installation should be supervised and/or verified by knowledgeable engineering personnel before the system is operated for checkouts and flushing.

Make sure the system is completely drained. During the initial draining of the systems, it was discovered that the systems were not designed to allow drainage of the main manifolds, downstream of the check valves, which held the oil in the system above the reservoirs. A hand valve was added to each system to allow the manifolds to be drained of the 100 gallons or so of oil that was captured in this area.

Anticipate that cleaning the system will take time. New oil should not be assumed to meet the NAS particulate specifications for the type of system in which it will be used. For these systems at the 10x10 SWT, a NAS of 5 to 6 is necessary. According to oil supply companies, the NAS level is generally 8 to 9 for "new" oil. Containers that are used to ship new oil should be cleaned prior to filling at the company. Oil shipped in barrels should be avoided and whenever possible only plastic bladders (or totes, ie. 320 gallon bladders in a wire cage) should be accepted.

4. APPENDIX

- ## 4.1. Selected Details of the Specialized Capabilities and Capabilities of the 10x10 SWT

This information can be found on the following sheets or on the NASA Glenn Research Center Facilities Home Page at: http://facilities.grc.nasa.gov.

- Home
- Description
- Capabilities
- Test Request Form
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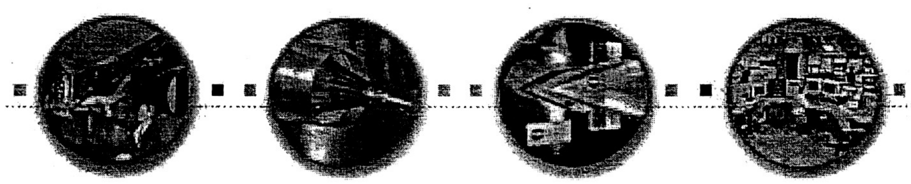
Abe Silverstein Supersonic Wind Tunnel: Facility Description

The Unitary Plan Act, passed by Congress in 1949, was a coordinated national plan of facility construction that encompassed the National Advisory Committee for Aeronautics (NACA), Air Force, industry, and universities. In 1956, under the leadership of Dr. Abe Silverstein and Eugene Wasliewski, the 10-by 10-Foot Supersonic Wind Tunnel (10x10 SWT) was brought on line. Dr. Silverstein was responsible for the Mercury program, and for all unmanned satellite programs for the first three years of the agency. He named the Apollo program and laid the groundwork for that program's success in landing a man on the moon. The facility was re-named the Abe Silverstein 10- by 10-Foot Supersonic Wind Tunnel in 1994 in recognition his accomplishments. Throughout its history, the tunnel has made valuable contributions to advancement of fundamental supersonic propulsion technology, the development of Atlas-Centaur, Saturn and Atlas-Agena class launch vehicles, and vehicle-focused research programs including the High-Speed Civil Transport, the National Aerospace Plane, and the Joint Strike Fighter.

The test section is 10 ft, high by 10 ft. wide by 40 ft. long and can accommodate large-scale models, full-scale engines and aircraft components. The 10x10 was specifically designed to test supersonic propulsion components such as inlets and nozzles, propulsion system integration, and full-scale jet and rocket engines. It can operate as a closed-loop system (aerodynamic cycle) or open-loop system (propulsion cycle), reaching test section speeds of Mach 2.0 to 3.5 and very low speeds from 0 to Mach 0.4. Gust and Mach plates are sometimes installed to expand local Mach number conditions between Mach 1.5 and 4.1. There is also a continuous operation across the entire speed and altitude regime, offering users greater flexibility and productivity during testing.



In the propulsion cycle, the tunnel operates by continuously drawing outside air through a very large air dryer to remove the moisture and exhausting it back into the outside environment. This mode is used for models that introduce contaminants into the air stream or use potentially explosive gas mixtures or when the tunnel air-heater is used to simulate flight temperatures. During the aerodynamic cycle, the tunnel runs as a closed system as variable density facility that can simulate pressure altitude conditions ranging from 50,000 to and 150,00 ft. Dry air is added to maintain test conditions.

The facility is controlled and operated by a digital distributed control system in order to maximize data quality while minimizing operational costs. Steady-state data is collected from the model instrumentation, processed, and displayed in engineering units and graphical formats at an update rate of one-per-second. Transient data with sampling rates of 2 MHz/sec and an optical instrumentation suite of capabilities are also used depending on test requirements. To increase test productivity, a test matrix sequencer automatically arranges model variables and facility parameters by using a pre-programmed test matrix. Real time transmission and display of all test data and information is provided to customer locations outside of NASA Glenn.

Specialized support systems and equipment include:

- Tunnel air heater
- Schlieren and advanced optical imagery (infrared, sheet lasers, LDV, PSP, TSP)
- High-pressure air
- Altitude exhaust
- Cooling water
- Hydraulics
- Gust/Mach Plates
- Liquid and gaseous fuel supplies
- Model sting/struts and adapters
- Variety of available research test hardware

For further technical information about the facility, please refer to the capabilities page for within this site.

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RResponsible NASA Official: Thomas B. Irvine
Site Curator: Sharon J. Maier, Indyne Inc.

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Abe Silverstein Supersonic Wind Tunnel: Facility Capabilities

The 10x10 SWT can be run in aerodynamic (closed-loop) mode or propulsion (open-loop) mode. It can also run at subsonic test conditions in aerodynamic and propulsion modes. Subsonic test conditions range from 5 to 240 kn and altitudes up to 50000 feet.

	Aerodynamic Mode	Propulsion Mode
Altitude (ft)	50,000 - 150,000	5,000 - 75,000
Reynolds No.	0.2 - 3.5 x 10^{-6}/ft	2.1 - 3.0 x 10^{-6}/ft
Mach No.	0 - 0.4 & 2.0 - 3.5	0 - 0.4 & 2.0 - 3.5

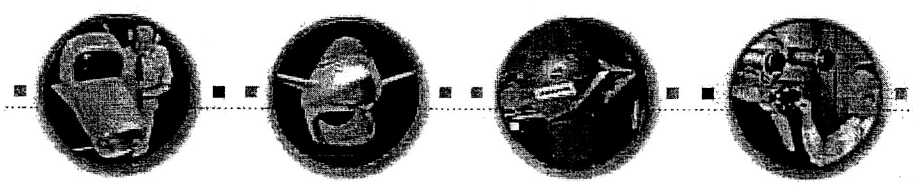
Tunnel Support Systems

High Pressure Air
- High pressure air 2600 psig variable (216000 scf storage)
- Combustion air 450 psig 12 lbm/s (300 °F max. temp)
- Service Air 125 psig 2 lbm/s

Hydraulics
- Model hydraulics 3000 psig 75 gpm

Fuels
- Gaseous and liquid hydrogen 1200 psig variable
- Liquid jet fuel 40 psig 70 gpm

Vacuum/Exhaust
- Model exhaust 20 lbm/s (2 lines at 10 lbm/s)



Model Support Systems:

- Ceiling Strut Assembly: angle of attack range between -5.0 and 15.0°
- Transonic Sting Strut Assembly: Floor mounted with angle of attack range between 0 and 15.0°
- Supersonic Strut: Floor mounted; axial movement
- Wall Mount: Typical of halfspan models
- Jet Exit Rig: Ceiling mounted strut with hot gas capabilities for nozzle research
- Gust Plates: Extends local conditions down to Mach Number 1.5 or up to Mach Number 4.1

Model Data and Control System Capabilities

Pressure Systems
- 1024 channel pressure measurement system
- Real-time data transfer and display to ESCORT
- Online calibration
- Pressure ranges from ± 2.5 psi to 500 psi
- Accuracy ± 0.05% of range

Data System - ESCORT
- 256 analog steady state channels
- Accuracy ± 0.05 percent of range
- Once per second update rate of all channels
- Acquires 1024 parameters from system per second
- Real-time display of calculations and parameters
- High resolution graphics and display pages
- X-window based system
- Self contained in facility control room
- Off-site access to data

Dynamic Data System
- 256 channel VME based transient acquisition system
- Sample and hold per channel
- Anti-aliasing filter amplifier (132 dB/Oct) per channel
- Online graphics and calculation
- Networked PC workstation for runtime analysis
- Off-site access to data

Flow Visualization
- Pressure sensitive paint
- Both conventional and focused Schlerien systems
- Sheet laser
- Oil flow visualization
- High speed video - up to 1000 full screen frames/s

Test Article Controls
- Digital model control system with graphical interface
- Automated test article sequencing system

Remote Access Control Room
- Real-time remote access to all data
- Video conferencing in real time
- Workstations supplied for remote site
- Secure network connections provided

RResponsible NASA Official: Thomas B. Irvine
Site Curator: Sharon J. Maier, Indyne Inc.